BIOLOGICAL EVALUATION FOR FEDERALLY ENDANGERED AND THREATENED DWARF WEDGEMUSSEL, NORTHERN LONG-EARED BAT, INDIANA BAT, AND NORTHEASTERN BULRUSH IN VERMONT:

An evaluation of the potential effects of state-adopted cadmium, phosphorus, and temperature aquatic life criteria

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Introduction

Federally protected species are listed as endangered or threatened under the Endangered Species Act (ESA). Section 7(a) of the Endangered Species Act of 1973, as amended, grants authority to and imposes requirements upon Federal agencies regarding endangered or threatened species of fish, wildlife, or plants ("listed species") and habitat of such species that has been designated as critical (a "critical habitat"). The ESA requires every Federal agency, in consultation with, and with the assistance of the Secretary of Interior, to insure that any action it authorizes, funds, or carries out, in the United States or upon the high seas, is not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of critical habitat. The United States Fish and Wildlife Service (USFWS) administers Section 7 consultations for freshwater species. The National Marine Fisheries Service (NMFS) administers Section 7 consultations for marine species and anadromous fish.

In 2016, the Vermont Department of Environmental Conservation (VT DEC) adopted, among other water quality standards, revised aquatic life criteria for temperature, phosphorus (P), and cadmium (Cd), applicable to waters under the state of Vermont's jurisdiction. The criteria can be found at the following link: http://dec.vermont.gov/sites/dec/files/documents/wsmd_water_quality_standards_2016.pdf. In 2017, VT DEC submitted the criteria to EPA for review and approval or disapproval pursuant to section 303 of the federal Clean Water Act.

EPA proposes to approve Vermont's revised aquatic life criteria. The purpose of this Biological Evaluation (BE) is to evaluate the potential effects that EPA's approval of the criteria may have on federally protected species, specifically the dwarf wedgemussel (*Alasmidonta heterodon*), Northeastern bulrush (*Scirpus ancistrochaetus*), Northern long-eared bat (*Myotis septentrionalis*) and Indiana bat (*M. sodalis*). This BE addresses EPA's proposed approval of the criteria in compliance with Section 7(c) of the ESA of 1973, as amended. Section 7 of the ESA assures that, through consultation (or conferencing for proposed species) with the USFWS and NMFS, federal actions do not jeopardize the continued existence of any threatened, endangered or proposed species, or result in the destruction or adverse modification of critical habitat. For the reasons set forth below, EPA believes that EPA's approval of Vermont's aquatic life criteria is not likely to adversely affect the listed species.

Project Description

Background

On December 16, 2016, the VT DEC adopted new and revised water quality standards, effective January 15, 2017, including revised temperature, phosphorus, and cadmium criteria for aquatic life use (Vermont DEC 2017). If approved by EPA, the criteria will be effective for all Clean Water Act purposes, including being the applicable instream criteria to protect aquatic life uses in Vermont's waters. Consistent with its obligations under the Endangered Species Act, the EPA Region 1 is consulting with the USFWS on the revised aquatic life criteria in advance of approving them. This Biological Evaluation addresses whether EPA's approval of the State's revised criteria is likely or unlikely to adversely affect federally listed endangered or threatened species in Vermont.

Action Area

The action area is defined in 50 CFR 402.02 as "all areas to be affected directly or indirectly by the Federal action and not merely the immediate area involved in the action." For purposes of this Section 7 consultation support document, the extent and location of the action area are defined as:

1.) the lowest stretch of the Black River in Vermont, approaching its confluence with the Connecticut River, that constitutes the estimated range of dwarf wedgemussel in the State (USFWS 2013);
2.) multiple locations in Windham and Windsor Counties for the Northeastern bulrush (von Oettingen 2019);
3.) Addison, Bennington, Chittenden, Orange, Rutland and Windsor Counties for the Indiana bat (von Oettingen 2019); and
4.) all of the State of Vermont for the Northern long-eared bat.

The map included in this BE illustrates the location within Vermont waters of the estimated range of dwarf wedgemussel in the lowest reach of the Black River (green line on the map), a tributary to the Connecticut River (USFWS 2007).[1]

Listed Species, Distinct Population Segments and Critical Habitat Within the Action Area

There is one endangered species of mollusk listed under the Endangered Species Act that occurs or has the potential to occur in the action area and may be affected by the proposed action. One species of endangered bulrush, one species of endangered bat, and one species of threatened bat occur in the action area. No critical habitat for any of these species has been designated in Vermont. The pertinent listing information for the species are identified in Tables 1-4 below:

Table 1. Federal Register Notices Related to the Dwarf Wedgemussel (*Alasmidonta heterodon*)
Status - Endangered

Title	Federal Register	Date
ETWP; Proposed Endangered Status for the Dwarf Wedge Mussel	54 FR 15236 15240	04/17/1989
ETWP; Determination of Endangered Status for the Dwarf Wedge Mussel	55 FR 9447 9451	03/14/1990
Initiation of a 5-Year Review of Nine Listed Species: including Dwarf Wedgemussel (*Alasmidonta heterodon*)	71 FR 20717 20718	04/21/2006

[1] The boundary between the States of Vermont and New Hampshire is the low water mark on the western side of the Connecticut River. See Vermont v. New Hampshire, 289 U.S. 593 (1933). Consequently, we expect that mussels in the mainstem of the Connecticut River, which would fall under New Hampshire's jurisdiction, will be protected by New Hampshire's recently revised cadmium criteria, which are the same as Vermont's. EPA is currently working on ESA consultation for the revisions to New Hampshire's cadmium criteria.

Endangered and Threatened Wildlife and Plants; Initiation of 5-Year Reviews of Nine Species: including Dwarf Wedgemussel	76 FR 33334 33336	06/08/2011

Table 2. Federal Register Notices Related to the Northeastern Bulrush (*Scirpus ancistrochaetus*)
Status - Endangered

Title	Federal Register	Date
ETWP; Proposed Endangered Status for Scirpus ancistrochaetus (Northeastern bulrush); 55 FR 46963 46968	55 FR 46963 46968	11/08/1990
ETWP; Determination of Endangered Status for Scirpus ancistrochaetus (Northeastern bulrush); 56 FR 21091 21096	56 FR 21091 21096	05/07/1991
Initiation of a 5-Year Review of 5 Listed Species: The Virginia Northern Flying Squirrel (Glaucomys sabrinus fuscus), Delmarva Peninsula Fox Squirrel (Sciurus niger cinereus), Northeastern Bulrush (Scirpus ancistrochaetus), Chittenango Ovate Amber Snail (Succinea chittenangoensis), and Virginia Round-Leaf Birch (Betula uber)	70 FR 38976	07/06/2005
Initiation of 5-Year Reviews of Five Listed Species: Delmarva Peninsula Fox Squirrel, Northeastern Bulrush, Furbish Lousewort, Chittenango Ovate Amber Snail, and Virginia Round-Leaf Birch	75 FR 47025 47026	08/04/2010

Table 3. Federal Register Notices Related to the Indiana Bat (*Myotis sodalis*)
Status - Endangered

Title	Federal Register	Date
Endangered Species List - 1967	32 FR 4001	03/11/1967
Proposed Determination of Critical Habitat for Snail Darter, American Crocodile, Whooping Crane, California Condor, Indiana Bat, and Florida Manatee (Percina (Imostoma) sp., Crocodylus acutus, Grus americana, Gymnogyps californicus, Myotis sodalis, Trichechus manatus)	40 FR 58308 - 58312	12/16/1975
Determination of Critical Habitat for American Crocodile, California Condor, Indiana Bat, and Florida Manatee (American crocodile, Crocodylus acutus, California condor, Gymnogyps californianus; Indiana bat, Myotis sodalis; Florida manatee, Trichechus manatus)	41 FR 41914	09/24/1976
Final Correction and Augumentation of Critical Habitat Reorganization	42 FR 47840 - 47845	09/22/1977

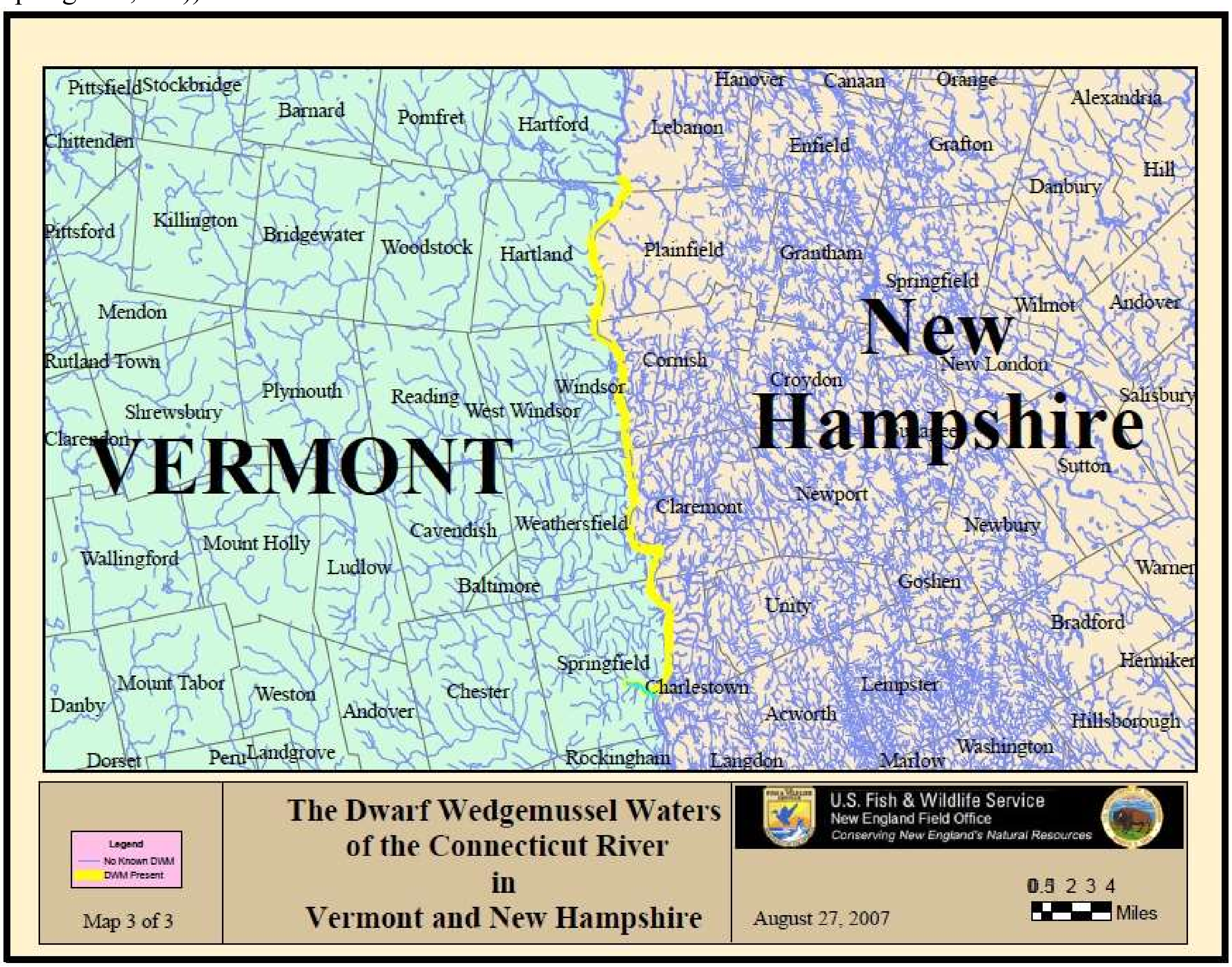
Endangered and Threatened Wildlife and Plants; Initiation of a 5-Year Review of Curtis' Pearlymussel and Indiana Bat	71 FR 55212 - 55214	09/21/2006
90-Day and 12-Month Findings on a Petition To Revise Critical Habitat for the Indiana Bat	72 FR 9913 - 9917	03/06/2007
Draft Indiana Bat Recovery Plan, First Revision; Draft Survey Protocol	72 FR 19015 - 19016	04/16/2007
5-Year Status Reviews of Seven Listed Species: Notice of initiation of reviews; request for information	76 FR 44564 - 44566	07/26/2011
Notice of availability draft EIS and HCP	77 FR 38819 - 38821	06/29/2012
Final Environmental Impact Statement, Habitat Conservation Plan, and Implementing Agreement and Draft Programmatic Agreement, Buckeye Wind Power Project, Champaign County, Ohio	78 FR 23586 - 23587	04/19/2013
Initiation of 5-Year Status Reviews of Nine Listed Animal and Two Listed Plant Species	79 FR 38560 - 38562	07/08/2014
Draft Environmental Assessment, Draft Habitat Conservation Plan, and Draft Implementing Agreement; Receipt of an Application for an Incidental Take Permit, Wildcat Wind Farm, Madison and Tipton Counties, Indiana	81 FR 39947	06/20/2016

Table 4. Federal Register Notices Related to the Northern Long-eared Bat (*Myotis septentrionalis*)
Status - Threatened

Title	Federal Register	Date
90-Day Finding on a Petition To List the Eastern Small-Footed Bat and the Northern Long-Eared Bat as Threatened or Endangered	76 FR 38095 - 38106	06/29/2011
12-Month Finding on a Petition To List the Eastern Small-Footed Bat and the Northern Long-Eared Bat as Endangered or Threatened Species; Listing the Northern Long-Eared Bat as an Endangered Species; Proposed Rule	78 FR 61045 - 61080	10/02/2013
Listing the Northern Long-Eared Bat as an Endangered Species	78 FR 72058 - 72059	12/02/2013
6-Month Extension of Final Determination on the Proposed Endangered Status for the Northern Long-Eared Bat	79 FR 36698 - 36699	06/30/2014
Endangered Species Status for the Northern Long-Eared Bat: Reopening of comment period	79 FR 68657 - 68659	11/18/2014
Listing the Northern Long-Eared Bat With a Rule Under Section 4(d) of the Act	80 FR 2371 - 2378	01/16/2015
Listing the Northern Long-Eared Bat With a Rule Under Section 4(d) of the Act; Correction	80 FR 5079	01/30/2015

Threatened Species Status for the Northern Long-Eared Bat With 4(d) Rule	80 FR 17973 - 18033	04/02/2015
4(d) Rule for the Northern Long-Eared Bat; Final rule	81 FR 1900 - 1922	01/14/2016
Determination That Designation of Critical Habitat Is Not Prudent for the Northern Long-Eared Bat: Critical habitat determination.	81 FR 24707 - 24714	04/27/2016
Draft Environmental Assessment, Draft Habitat Conservation Plan, and Draft Implementing Agreement; Receipt of an Application for an Incidental Take Permit, Wildcat Wind Farm, Madison and Tipton Counties, Indiana	81 FR 39947	06/20/2016

Map 1. Estimated range of dwarf wedgemussel, Black River in Vermont (depicted in green, southeast of Springfield, VT))



Temperature Criteria for Fresh Waters

The revised temperature criteria are only applicable to cold water fish habitat, in Class A(1) and B(1) waters for fishing. Previously Vermont had a single coldwater criterion for all classes. The new criteria allow no change in temperature to Class A(1) waters and increase the existing level of protection from temperature increases for Class B(1) waters. The lowest stretch of the Black River in Vermont, where it approaches its confluence with the Connecticut River is classified as warm water. Consequently, the new criteria are not applicable to the Action Area for Dwarf Wedgemussel, and therefore EPA finds the temperature criteria will have No Effect on the mussel.

The wetlands adjacent to the Connecticut River are classified as warm water and therefore the new criteria are not applicable to the Northeastern bulrush in that habitat. The bulrush also resides in various low gradient beaver flowages, exposed mudflats adjacent to low gradient streams, perched swamps, and impoundments (Popp 2019). The new criteria are not applicable to any of those bulrush habitats that are warm water, and therefore will have No Effect on the bulrush in such habitats. For those habitats (if any) that are classified as cold water fish habitat, Class (A)(1) or (B)(1) waters for fishing, EPA finds that the more protective temperature criteria are not likely to adversely affect the Northeastern bulrush, and may provide benefits to the bulrush by reducing the potential for temperature rise in those habitats.

The two bat species are only affected by water temperature through effects on their aquatic insect prey. The proposed criteria will either not change cold water temperature standards, or be more protective of cold water resources, including aquatic invertebrates, depending on the stream type. Therefore, we do not expect negative impacts to the prey species of the Indiana and Northern long-eared bats (i.e. aquatic invertebrates) which thrive in cold water environments. Consequently, EPA finds the temperature criteria are not likely to adversely affect the bats as a result of effects on prey in coldwater Class A(1) and B(1) waters for fishing, and the criteria may have a beneficial effect. EPA also finds that the revised temperature criteria will have No Effect on bats from impacts to prey in cold waters that are not Class A(1) or B(1) waters for fishing because the criteria do not apply to such waters.

Table 5. Final effect determinations for temperature, for aquatic and aquatic-dependent listed species occurring in Vermont that may be affected by the approval action.

Species	Final Effects Determination for Temperature
Dwarf wedgemussel (*Alasmidonta heterodon*)	***No Effect***
Northern long-eared bat (*Myotis septentrionalis*)	***No Effect/Not Likely to Adversely Affect (NLAA)*** *Depending on the habitat, there will either be no effect, or possibly a beneficial effect on the species*
Indiana bat (*M. Sodalis)*	***No Effect/Not Likely to Adversely Affect (NLAA)*** *Depending on the habitat, there will either be no effect, or possibly a beneficial effect on the species*
Northeastern bulrush (*Scirpus ancistrochaetus*)	***No Effect/Not Likely to Adversely Affect (NLAA)*** *Depending on the habitat, there will either be no effect, or possibly a beneficial effect on the species*

Phosphorus Criteria for Fresh Waters

Prior to the 2017 WQS revisions, Vermont DEC had adopted, and EPA had approved, numeric total phosporous (TP) criteria for small and medium high-gradient and warm water medium-gradient flowing waters that are classified as A(1), A(2) and B in its Water Quality Standards (2014). Vermont is the only state in New England with numeric TP criteria for flowing waters. The 2014 criteria are some of the lowest existing anywhere for such waters in the United States, and are designed to discourage the growth of nuisance plant growth in Vermont streams.

A substantial achievement in the Vermont standards package adopted January 2017 is the creation of a high quality class B water, noted as Class B(1). At the same time, all other remaining, former B waters, the criteria for which were approved by EPA in 2014, became Class B(2) (Table 6).

Table 6: Vermont phosphorus flowing waters criteria, changes from 2014 to 2017 in revised water quality standards (Vermont DEC 2017).

Stream water quality classification	Small, high-gradient streams	Medium, high-gradient streams	Warm-water, medium-gradient streams
Nutrient criteria concentrations: Total phosphorus (ug/L)			
2014 Class B 2017 Class B(2)	12	15	27
2017 Class B(1)	10	9	21

The Black River where the mussels are found is classified as Class B(2), Warm-Water Medium Gradient. The TP criterion for these waters is 27 ug/L and did not change with the 2017 standards revision. Because the new, revised criteria are not applicable to mussel habitat in the State, EPA finds the criteria will have No Effect on the dwarf wedgemussel.

Habitats where the Northeastern bulrush are found (see Temperature section, above) are either not covered by the new criteria, or the criteria have become more stringent and protective. Consequently, in waters where the new criteria are not applicable, Class A(1), A(2), and B(2) waters, EPA finds there will be No Effect to the bulrush. EPA also finds that the revised criteria are Not Likely to Adversely Affect the bulrush in habitats where they are applicable, Class B(1) waters. Because the revised criteria are more stringent than the current criteria, they may also have a beneficial effect on the species.

Phosphates, the most common form of phosphorus found in the environment, are not toxic to people or animals unless they are present in high levels (Fadiran et al. 2008; Kim et al 2013). Vermont's phosphorus criteria ensure that levels will be low enough to prevent excessive algae growth, and there is no evidence that such levels will strip needed phosphorus from the environment. Consequently, bats will not be adversely affected by the phosphorus in the water they drink, and there should be no adverse effect to their aquatic insect prey. EPA finds that there will be No Effect to the bats in waters where there has been no change to the criteria, Class A(1), A(2), and B(2) waters. The revised criteria are Not Likely to Adversely Affect the bats in habitats where they are applicable, Class B(1) waters. Because the revised criteria are more stringent than the current criteria, they may also have a beneficial effect on the species.

Table 7. Final effect determinations for phosphorus, for aquatic and aquatic-dependent listed species occurring in Vermont that may be affected by the approval action.

Species	Final Effects Determination for Phosphorus
Dwarf wedgemussel (*Alasmidonta heterodon*)	***No Effect***
Northern long-eared bat (*Myotis septentrionalis*)	***No Effect/Not Likely to Adversely Affect (NLAA)*** *Depending on the habitat, there will either be no effect, or possibly a beneficial effect on the species*
Indiana bat (*M. Sodalis)*	***No Effect/Not Likely to Adversely Affect (NLAA)*** *Depending on the habitat, there will either be no effect, or possibly a beneficial effect on the species*
Northeastern bulrush (*Scirpus ancistrochaetus*)	***No Effect/Not Likely to Adversely Affect (NLAA)*** *Depending on the habitat, there will either be no effect, or possibly a beneficial effect on the species*

Cadmium Stressor Analysis

Stressor Sources

Cadmium is a naturally occurring metal found in mineral deposits and distributed widely at low concentrations in the environment (USEPA 2016). The primary current industrial uses of cadmium are for manufacturing batteries, pigments, plastic stabilizers, metal coatings, alloys and electronics, and in the manufacture of nonoparticles (Fulkerson and Goeller 1973; Hutton 1983; Pickering and Gast 1972; Wilson 1988). Cadmium is also present in mine wastes, fossil fuels, iron and steel, cement, and fertilizers (Cook and Morrow 1995). The agricultural application of phosphorus fertilizers is one of the main sources of cadmium to the environment (Pan et al. 2010; Panagapko 2007). Cadmium also enters the environment as a result of weathering and erosion of rock and soils and natural combustion of volcanoes and forest fires (Hem 1992; Hutton 1983; Pickering and Gast 1972; Shevchenkl et al. 2003; USEPA 2016a; WHO 2010).

Mode of Action and Toxicity

Cadmium is a non-essential metal with no biological function in aquatic animals (Eisler 1985; Lee et al. 1995; McGeer et al. 2012; Price and Morel 1990; Shanker 2008). In addition to its acute toxicity, cadmium is a known teratogen and carcinogen, is a probable mutagen, and is known to induce a variety of other short-and long-term adverse physiological effects in fish and wildlife at both the cellular and whole animal level (ATSDR 2012; Eisler 1985; Okocha and Adedeji 2011). Chronic exposure leads to adverse effects on growth, reproduction, immune and endocrine systems, development, and behavior in aquatic organisms (McGeer et al. 2012). Other toxic effects include histopathologies of the gill, liver and kidney in fish, renal tubular damage, alterations of free radical production and the antioxidant defense system, immunosuppression, and structural effects on invertebrate gills (Goaro et al. 2007; Jarup et al. 1998; McGeer et al. 2011; Okacha and Adedeji 2011; Shanker 2008; USEPA 2016)

Freshwater biota are the most sensitive to cadmium, and marine organisms are generally considered to be more resistant than freshwater organisms (Burger 2007; Eisler 1985; USEPA 2016).

Water hardness, which is the amount of minerals (primarily calcium and to a lesser extent magnesium) dissolved in surface water, is one important water quality parameter influencing the toxicity of cadmium (USEPA 2016). The acute toxicity of cadmium has been shown to increase with decreasing water hardness in most tested freshwater animals (Sprague 1985). Levels of dissolved organic carbon (DOC) have also been shown to affect toxicity, with greater DOC reducing cadmium toxicity (USEPA 2016).

Environmental Fate

Upon entering the aquatic environment, cadmium is strongly adsorbed to clays, and humic and organic materials (Watson 1973), and these complexes are removed from the water column by precipitation (Lawrence et al. 1996). Once in sediments, it can be re-suspended in particulate form or can return to the water column in dissolved form following hydrolosis or via upwelling in coastal zones (Bewers et al. 1987; USEPA 1979; USEPA 2016).

Conceptual Model

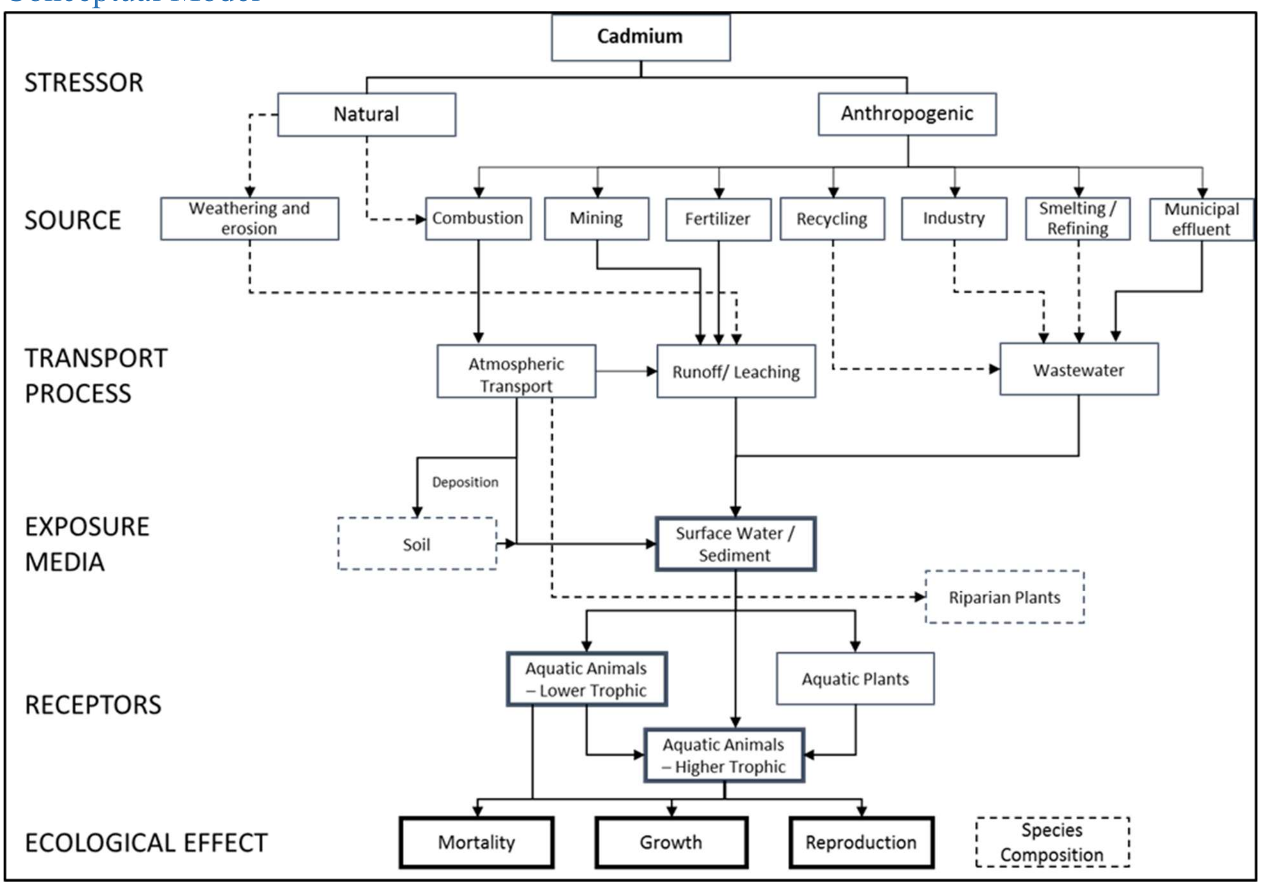


Figure 1. Conceptual Model Depicting the Major Sources, Transport and Exposure Media and Ecological Effects of Cadmium in the Environment. (Note: Solid line indicates potentially important pathway/media/receptor; dashed line indicates secondary pathway/media/receptor). **(USEPA 2016)**

Cadmium Effects Analysis:

Cadmium Criteria for Fresh Waters

Vermont adopted EPA's recommended cadmium criteria from EPA's March 2016 criteria update document, which takes into account scientific data on acute and chronic toxicity made available since the 2001 criteria update, including toxicity data related to hardness, which continues to be the major quantitative correlation used to modify metal toxicity estimates in fresh water. The 2016 update also examined the acceptable duration of tests using the mussel larval stage, glochidia, which remain viable in the water column for a limited period post hatching and before they attach to a host fish. The examination was driven by a concern for the sensitivity of the glochidia stage as it plays an important role in the viability of the freshwater mussel (Unionidae family) population. That examination determined that the glochidia were less sensitive to toxicity than the juvenile stage for the freshwater mussel population (EPA 2016).

The cadmium criteria magnitude is affected by hardness. The acute criterion duration represents a one-hour average. The chronic criterion duration represents a 30-day rolling average with the additional restriction that the highest 4-day average within the 30 days be no greater than 2.5 times the chronic criterion magnitude. These values are not to be exceeded more than once in 3 years on average (USEPA 2016).

1 Cadmium Effects Assessment Methodologies

1.1 Dwarf Wedgemussel Effects Assessment Methodologies

EPA made an acute effects determination for the dwarf wedgemussel by first assessing the protectiveness of the acute criterion magnitude. Assessing the acute criterion magnitude alone does not consider the duration and frequency components of the criterion and represents an overly conservative exposure scenario that assumes cadmium concentrations in all Vermont freshwaters will be at the acute criterion magnitude indefinitely.

EPA (2016) states, "*measured concentrations of cadmium can be expressed as either total recoverable cadmium, acid-soluble cadmium, or total dissolved cadmium (using a conversion factor) based on the different forms of cadmium present in the aquatic environment. Previous aquatic life criteria for cadmium were expressed either in terms of total recoverable cadmium (U.S. EPA 1980; 1983) or as acid-soluble cadmium (U.S. EPA 1985). Since 1993, EPA has recommended using dissolved metal concentrations (defined as the metal in solution that passes through a 0.45- µm membrane filter) for developing criteria, based on the greater bioavailability of dissolved metals in surface water. Cadmium criteria are accordingly expressed as dissolved metal concentrations consistent with current recommendations (Prothro 1993; U.S. EPA 1993, 1994), which typically involves converting measured total recoverable cadmium concentrations to estimated dissolved cadmium concentrations using a conversion factor*":

- Dissolved acute concentration = total concentration X (1.136672 – [(ln hardness)(0.041838)]);
- Dissoved chronic concentration = total concentration X (1.101672 - [(ln hardness)(0.041838)]).

EPA's 2016 cadmium criteria were derived using total cadmium concentrations reported in toxicity tests and then, as a final step, were converted to represent dissolved cadmium concentrations. Consistent with the criteria derivation process, the effects assessment reported here considers toxicity test results based on total cadmium concentrations. Assessing the protectiveness of cadmium criteria using total cadmium produces the same conclusions as basing the assessment on dissolved cadmium because the total to dissolved conversion is fundamentally consistent between the criteria and test waters used to support the effects assessment.

1.1.1 Dwarf Wedgemusssel Acute Effect Assessment Methodology: Residential Exposure Effects

The protectiveness of the acute criterion magnitude was assessed by identifying or estimating acute toxicity values for the dwarf wedgemussel. Acute toxicity values used to develop the acute effects assessment were obtained from Appendix A of the Cadmium 304(a) aquatic life criteria document (USEPA 2016. Appendix A; 2016 Species Mean Acute Values [SMAV]). These data were identified from EPA's ECOTOX database, open literature, and grey literature and have been subject to extensive data quality review (USEPA 1985). Ideally, species-specific toxicity data are available to support an acute effects assessment; however, data limitations (i.e., no available data specific to the dwarf wedgemussel) required the use of surrogate toxicity data. Acute toxicity data used to support the effects assessment have been previously normalized to a water hardness of 100 mg/L, consistent with criteria derivation.

EPA considered acute toxicity data at the closest taxonomic level available to determine a geometric mean toxicity value representative of the dwarf wedgemussel. Considering surrogate toxicity data at the most phylogenetically-related taxonomic level possible accounts for genetically-derived traits conserved across taxa that may directly influence species and taxa sensitivity to a pollutant. Surrogate toxicity data obtained from Appendix A of the aquatic life criteria document (USEPA 2016) represent the relative sensitivity of the dwarf wedgemussel expressed as a concentration that will kill half of the test population (i.e., LC_{50}). EPA then transformed the acute toxicity data (expressed as LC_{50}) to an acute low effect threshold value that represents a cadmium concentration that is not expected to kill more than five percent of the dwarf wedgemussel (i.e., LC_5) under continuous exposure conditions. Representing acute low effect thresholds as LC_5 values is conservative considering high-quality toxicity tests are considered acceptable when demonstrating up to 10 percent lethal effects in control (unexposed to cadmium) organisms, typically resulting from natural mortality. That is, at effect levels below ten percent, it is often difficult to distinguish whether or not observed responses are the effect of natural morality or pollutant exposures themselves.

Raw acute toxicity data may be used to calculate LC_5 values directly from the concentration-response (C-R) curves of the listed species-specific toxicity tests, when available. However, not all acute tests provide concentration-response data. Therefore, species-specific, or surrogate LC_{50} values (which represent listed species 50% effect level), were transformed to an acute low effect threshold concentration through the use of an acute taxonomic adjustment factor (TAF) or an acute mean adjustment factor (MAF). An acute TAF was calculated by averaging (geometric mean) the ratios of LC_{50}:LC_5 from cadmium toxicity tests conducted using species in the closest possible phylogenetic proximity (same species, genus, family, or order) as the listed species that is being assessed. When data availability did not allow for the development of an acute TAF within the same order as the species being assessed, EPA considered applying an acute invertebrate or vertebrate TAF (depending on whether the listed species assessed was an invertebrate or vertebrate). The acute invertebrate TAF and the acute vertebrate TAF were calculated as the geometric mean of genus-level LC_{50}:LC_5 ratios of invertebrates and vertebrates, respectively. An acute MAF was used to adjust species effect concentrations (i.e., LC_{50}) to low effect threshold concentrations (i.e., LC_5) when; 1) an acute TAF is not available within the same order as the listed species being assessed and 2) when the acute invertebrate TAF and the acute vertebrate TAF were not significantly different via a two-sample t-test assuming unequal variances ($\alpha = 0.05$). The acute MAF is calculated as the geometric mean of all genus-level LC_{50}:LC_5 ratios available. Acute invertebrate and vertebrate TAFs and the acute MAF are calculated as the geometric mean of their respective genus-level LC_{50}:LC_5 ratios to limit the influence of LC_{50}:LC_5 ratios from species that are overly represented in a dataset, similar to criteria derivation (USEPA 1985).

Listed species-specific or surrogate LC_{50} values were then divided by an appropriate adjustment factor (i.e., acute TAF or acute MAF depending on data availability) to derive an acute low effect threshold concentration. Dividing LC_{50} values by an adjustment factor to identify a low-level effect concentration is an approach that is fundamentally similar to acute criteria derivation[2], but is more specific to the chemical and species assessed. Acute low effect threshold concentrations were then compared to corresponding criteria magnitudes (i.e., criterion maximum concentration [CMC]) to assess potential adverse effects of cadmium exposures at the acute criterion concentration over conservative exposure durations.

Dividing LC_{50} values by an adjustment factor to identify a low-level effect concentration (LC_{low}) is an approach that is fundamentally similar to acute criteria derivation but is more specific to cadmium and the dwarf wedgemussel.

Assessing a criterion magnitude alone does not consider the duration and frequency components of the criterion and represents an overly conservative exposure scenario that assumes a pollutant concentration in all Vermont freshwaters will be at the acute criterion magnitude indefinitely. If a listed species' acute low effect threshold concentration is greater than the corresponding acute criterion magnitude, then a refined assessment and consideration of the criterion duration and realistic exposure is not necessary, and approval of the acute criterion is not likely to adversely affect that particular listed species through acute effects in freshwaters.

Species sensitivity to cadmium is dependent on water hardness, with tolerance increasing as hardness increases (see USEPA 2016). The CMC increases with increasing hardness across the

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[2] The cadmium Final Acute Value (FAV; 5th percentile of genus mean acute values) was divided by 2.0 to derive the Criterion Maximum Concentration (CMC). The FAV was divided by 2.0 to ensure the CMC is representative of a concentration that will result in low level effects (e.g., 0-10%) to the 5th percentile of sensitive genera. EPA's 1978 proposed guidelines for deriving criteria (43 Fed. Reg. 21425, 21506-21518 (May 18, 1978)) outlined the derivation of a generic LC_{50} to LC_{low} (i.e., 0 – 10 % effect) adjustment factor of 0.44 (or divide by 2.27). The adjustment factor of 2.27 was derived as the "geometric mean of the quotients of the highest concentration that killed 0-10% of the organisms divided by the LC_{50} in 219 acute toxicity tests." The geometric mean adjustment factor (2.27) outlined in the 1978 proposal was subsequently rounded to 2.0 in EPA's final 1985 Guidelines (USEPA 1985).

range of hardness in typical ambient surface water (acute toxicity hardness slope 0.9789). Figure 1-1 depicts the change in the cadmium CMC across water hardness of 25 to 400 mg/L as $CaCO_3$, and how the acute low effect threshold for dwarf wedgemussel (from Section 2.1.1.3) changes with the criterion magnitude proportionally (factor difference of 14.94). The acute effects assessment was developed using toxicity data normalized to a reference condition (hardness = 100 mg/L) and compared to the corresponding CMC in those same reference conditions. Because species sensitivity and the CMC both change similarly across water chemistries, conclusions based on reference conditions translate to other water chemistries.

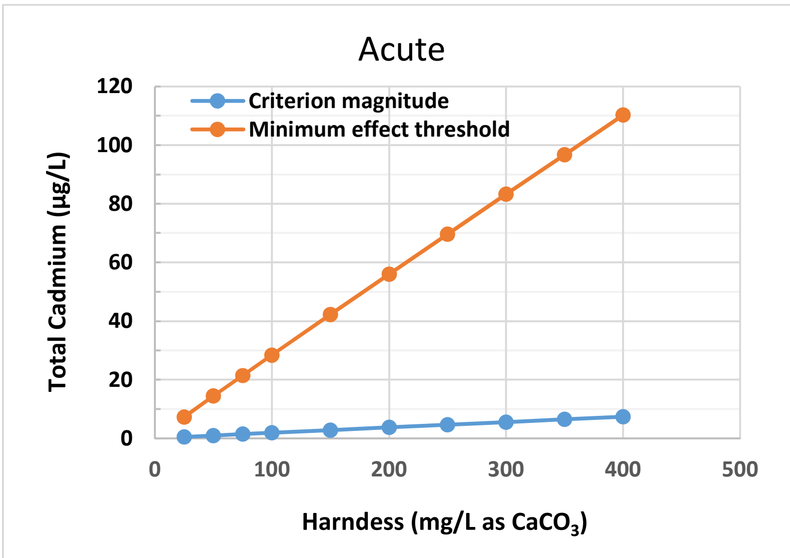

Figure 1-1. Acute cadmium criterion magnitudes extrapolated across a gradient of water hardness, overlaid with the dwarf wedgemussel acute low effect threshold concentration (Section 2.1.1.3 of this document). The cadmium criterion magnitude and the dwarf wedgemussel acute low effect threshold both increase with increasing water hardness. The factor difference between the acute criterion magnitude and acute low effect threshold for dwarf wedgemussel is 14.94.

1.1.2 Dwarf Wedgemussel Chronic Effect Assessment Methodology: Residential Exposure Effects

The protectiveness of the chronic criterion magnitude was assessed by identifying or estimating chronic toxicity values for the dwarf wedgemussel that were then adjusted to represent protective low effect threshold concentrations as described below. Chronic toxicity values used to develop the chronic effects assessment were obtained from Appendix C of the Cadmium 304(a) aquatic life criteria document (USEPA 2016. Appendix C; 2016 Species Mean Chronic Values [SMCV]). These data were identified from EPA's ECOTOX database, open literature, and grey literature and have been subject to extensive data quality review (USEPA 1985). Chronic cadmium toxicity data used to support the effects assessment have been previously normalized to a water hardness of 100 mg/L, consistent with criteria derivation (USEPA 2016).

Ideally, species-specific toxicity data are available to support a chronic effects assessment; however, similar to acute toxicity discussed above, data limitations required the use of surrogate chronic toxicity data. Unlike the acute criterion derivation, which typically uses a generic LC_{50} to

LC_{low} adjustment factor (i.e., 2.0 -- see footnote 2, above; USEPA 1985), the chronic criterion is based directly on chronic effect concentrations (i.e., EC_{20}, which represents a 20 percent effect/inhibition concentration) [USEPA 1985]. Because a concentration that results in chronic effects to 20% of an exposed listed species population could be considered excessively high, EPA developed adjustment factors to transform EC_{20} to EC_5 to represent a chronic low effect threshold concentration (EC_5), following an approach similar to the acute effects assessment methodology discussed above.

Raw chronic toxicity data may be used to calculate EC_5 values directly from the concentration-response (C-R) curves of the listed species-specific toxicity tests, when available. However, not all chronic tests provide concentration-response data. Therefore, species-specific, or surrogate EC_{20} values (which represent listed species 20% effect level), were transformed to a chronic low effect threshold concentration through the use of a chronic taxonomic adjustment factor (TAF) or a chronic mean adjustment factor (MAF). A chronic TAF was calculated by averaging (geometric mean) the ratios of EC_{20}:EC_5 from cadmium toxicity tests conducted using species in the closest possible phylogenetic proximity (same species, genus, family, or order) as the listed species that is being assessed. When data availability did not allow for the development of a chronic TAF within the same order as the species being assessed, EPA considered applying a chronic invertebrate or vertebrate TAF (depending on whether the species assessed was an invertebrate or vertebrate; in the case of Vermont, the only aquatic animal assessed was an invertebrate). The chronic invertebrate TAF and the chronic vertebrate TAF were calculated as the geometric mean of genus-level EC_{20}:EC_5 ratios of invertebrates and vertebrates, respectively. A chronic MAF was used to adjust species effect concentrations (i.e., EC_{20}) to low effect threshold concentrations (i.e., EC_5) when 1) a chronic TAF is not available within the same order as the listed species being assessed, and 2) when the chronic invertebrate TAF and the chronic vertebrate TAF were not significantly different via a two-sample t-test assuming unequal variances ($\alpha = 0.05$). The chronic MAF is calculated as the geometric mean of all genus-level EC_{20}:EC_5 ratios available. Chronic invertebrate and vertebrate TAFs and the chronic MAF are calculated as the geometric mean of their respective genus-level EC_{20}:EC_5 ratios to limit the influence of EC_{20}:EC_5 ratios from species that are overly represented in a dataset, similar to criteria derivation (USEPA 1985).

Listed species-specific or surrogate EC_{20} values were then divided by an appropriate adjustment factor (i.e., chronic TAF or chronic MAF depending on data availability) to derive a chronic low effect threshold concentration. Chronic low effect threshold concentrations were then compared to the chronic criterion magnitude (i.e., criterion continuous concentration [CCC]) to assess potential adverse effects of cadmium exposures at the chronic criterion concentration.

Species sensitivity to cadmium is dependent on water hardness, with tolerance increasing as hardness increases (see USEPA 2016). The CCC increases with increasing hardness across the range of hardness typical of natural ambient surface water, but with a slightly lower slope than for the CMC (chronic toxicity hardness slope 0.7977). Figure 1-2 depicts the change in the cadmium CCC across water hardness of 25 to 400 mg/L as $CaCO_3$, and how the chronic low effect threshold for dwarf wedgemussel (from Section 2.1.2.3) changes with the criterion magnitude proportionally (factor difference of 9.5). The chronic effects assessment was developed using toxicity data normalized to a reference condition (hardness = 100 mg/L) and compared to the corresponding CCC in those same reference conditions. Because species sensitivity and the CCC both change similarly across water chemistries, conclusions based on reference conditions translate to other water chemistries.

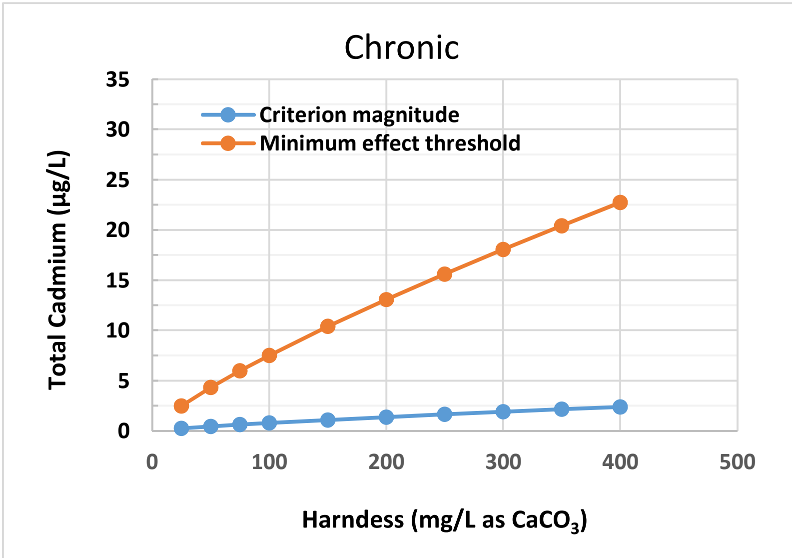

Figure 1-2. Chronic cadmium criterion magnitudes extrapolated across a gradient of water hardness overlaid with the dwarf wedgemussel chronic low effect threshold concentration (Section 2.1.2.3 of this document). The criterion magnitude increases and the dwarf wedgemussel chronic low effect threshold both increase with increasing water hardness. The factor difference between the chronic criterion magnitude and chronic low effect threshold for dwarf wedgemussel is 9.5.

Assessing a criterion magnitude alone does not consider the duration and frequency components of the criterion and represents an overly conservative exposure scenario that assumes a pollutant concentration in all Vermont freshwaters will be at the chronic criterion magnitude indefinitely. If a listed species' chronic low effect threshold concentration is greater than the corresponding chronic criterion magnitude, then a refined assessment and consideration of the criterion duration and realistic exposure is not necessary, and approval of the chronic criterion is not likely to adversely affect that particular listed species through chronic effects in freshwaters.

1.2 Other Effects (All listed species): Assessment of Acute and Chronic Criteria

Following assessment of acute and chronic effects, EPA considered and assessed potential other (non-residential) effects of the water quality standard approval actions on the listed species. To assess those potential effects, EPA considered conservatisms associated with criteria derivation and implementation as well as potential effects to listed species' prey items and on host fish for the mussels.

1.3 Conclusion (All listed species): Final Effects Determinations

Final effect determinations were based on the effects of EPA's approval of the acute and chronic cadmium criteria in Vermont. For aquatic listed species (dwarf wedgemussel and Northeastern bulrush), EPA considered the acute and chronic effects of residential exposure, as well as effects on host fish for the mussel, to make a final effects determination. For aquatic-dependent listed species (the Northern long-eared and Indiana bats) EPA concludes there will be no effects as a result of meaningful residential exposure and made a final effects determination based on the effects of cadmium on prey and ingesting drinking water.

2 Cadmium Effects Assessment

2.1 Dwarf Wedgemussel (*Alasmidonta heterodon*)

2.1.1 Dwarf Wedgemussel Acute Cadmium Residential Exposure Effects Assessment

2.1.1.1 Identifying Dwarf Wedgemussel Acute Cadmium Data

High quality species-level or genus-level acute cadmium toxicity data are not available for the dwarf wedgemussel. Family-level acute toxicity data were, therefore, used to determine an acute toxicity value (i.e., LC_{50}) of 65.58 µg/L (normalized to a total hardness of 100 mg/L as $CaCO_3$) representative of the dwarf wedgemussel (Table 8). Acute toxicity data were obtained from Appendix A of USEPA (2016) and were used to derive the acute freshwater criterion. The Family Mean Acute Value (FMAV) is based on six Genus Mean Acute Values (GMAV). Five of the six GMAVs are composed of single Species Mean Acute Values (SMAVs), with the exception of the genus *Lampsilis*, which is based on four SMAVs.

Table 8. Data used to calculate the Unionidae FMAV representative of dwarf wedgemussel acute sensitivity to cadmium.

Common	Species	SMAV[ab] (µg/L)	Genus	GMAV[ac] (µg/L)	Family	FMAV[ac] (µg/L)
Neosho mucket	*Lampsilis rafinesqueana*	44.67	*Lampsilis*	51.34	*Unionidae*	65.58
Fatmucket	*Lampsilis siliquoidea*	35.73				
Southern Fatmucket	*Lampsilis straminea claibornensis*	93.17				
Yellow sandshell	*Lampsilis teres*	46.71				
Mussel	*Actinonaias pectorosa*	67.9	*Actinonaias*	67.9		
Green floater	*Lasmigona subviridis*	68.51	*Lasmigona*	68.51		
Paper pondshell	*Utterbackia imbecillis*	71.76	*Utterbackia*	71.76		
Southern Rainbow	*Villosa vibex*	70.76	*Villosa*	70.76		
Dwarf wedge	*Alasmidonta heterodon*	N/A	*Alasmidonta*	N/A		

[a] All acute toxicity data have been normalized to a hardness of 100 mg/L (as $CaCO_3$) and expressed as total cadmium, consistent with Appendix A of the 2016 Cadmium 304(a) Aquatic Life Criteria document (USEPA 2016).
[b] SMAVs were obtained from Appendix A of the 2016 Cadmium 304(a) Aquatic Life Criteria document and organized based on taxonomy.
N/A : not available
[c] GMAVs and FMAVs were calculated as the geometric mean of lower taxonomic-level geometric mean values, since these mean values are meant to represent the sensitivity for a particular taxon.

2.1.1.2 Deriving LC_{50} to LC_5 Acute Adjustment Factor

Raw acute toxicity data are only available from two tests out of the several that were used to calculate the surrogate FMAV representative of the dwarf wedgemussel [tests with 5-d old juvenile Neosho mucket (*Lampsilis rafinesqueana*) and fatmucket (*L. siliquoidea*) reported by Wang et al. (2010)]. The C-R models for the two tests, however, are unacceptable (see Cd-Acute-15 and Cd-Acute-16 in Appendix VT.2). The C-R model for the Neosho mucket (Cd-Acute-15) does not provide a unique solution and was flagged in TRAP for inadequate partials, while the C-R model for the fatmucket (Cd-Acute-16) is a poor fit. No other acute toxicity tests with C-R data are available for the Order Unionoida. As a result, EPA obtained and analyzed raw C-R data for all tests used to derive the acute cadmium criterion (underlined values in Appendix A of USEPA 2016; Table 2-2) where such data were reported or could be obtained to derive an acute vertebrate TAF or acute MAF, if necessary (i.e., if the vertebrate and invertebrate-level acute TAFs differ from one another).

Raw acute toxicity data were fit to C-R models using EPA's TRAP software to calculate LC_{50} and corresponding LC_5 values for 69 tests representing 28 species (18 invertebrate and 10 vertebrates, including an amphibian). C-R models were excluded from TAF and MAF calculation if 1) models did not exhibit a unique solution and were flagged by TRAP as having inadequate partials; 2) models did not include observations in the region of interest which did not allow TRAP to accurately model a no-response plateau; and 3) models exhibited incongruities such as no or poor fit to key points or excessive noise in the C-R relationship. After exclusion of these unacceptable or questionable LC_{50}:LC_5 ratios for use in calculating an acute MAF, 35 ratios remained resulting in seven genus-level LC_{50}:LC_5 ratios for invertebrate species (arithmetic mean = 2.857 µg/L, variance = 2.186 µg/L) and six genus-level LC_{50}:LC_5 ratios for vertebrate species (arithmetic mean = 2.106 µg/L, variance = 0.2589 µg/L). Analysis of the two arithmetic means via a two sample t-test assuming unequal variances ($\alpha = 0.05$) indicated the means are the same *(t stat [1.259] < t critical for two tail [2.306]*). As a result, the acute MAF was used to transform the *Acipenser* GMAV representative of dwarf wedgemussel to an acute low effect threshold concentration.

Table 9 provides the 13 genus-level LC_{50}:LC_5 ratios used to derive the cadmium acute MAF. The acute MAF calculated as the geometric mean of all genus-level LC_{50}:LC_5 ratios is 2.310 (see Appendix VT.1 [attached as a separate file: *Appendix_VT_Cadmium_C_R_Data*] for raw toxicity test data, TRAP models and outputs for the 35 acute cadmium toxicity tests used to derive the acute MAF; Appendix VT.2 includes the raw toxicity data, TRAP models and output for all unacceptable and questionable acute cadmium toxicity tests).

Table 9. Acute $LC_{50}:LC_5$ ratios from analysis of 35 high-quality acute cadmium toxicity tests with freshwater aquatic organisms used to derive an acute mean adjustment factor (MAF) for the dwarf wedgemussel.

Order	Family	Species	LC_{50} (µg/L)	LC_{05} (µg/L)	$LC_{50}:LC_{05}$	C-R Curve Label	Reference	Species-level TAF ($LC_{50}:LC_{05}$)	Genus-level TAF ($LC_{50}:LC_{05}$)
Tubificida	Naididae	Tubificid worm, *Tubifex tubifex*	56,141	27,732	2.024	Cd-Acute-2	Rathore and Khangarot 2002	2.278	2.278
Tubificida	Naididae	Tubificid worm, *Tubifex tubifex*	26,650	10,289	2.590	Cd-Acute-5	Rathore and Khangarot 2002		
Tubificida	Naididae	Tubificid worm, *Tubifex tubifex*	423.3	299.5	1.414	Cd-Acute-6	Rathore and Khangarot 2003		
Tubificida	Naididae	Tubificid worm, *Tubifex tubifex*	6,463	1,778	3.634	Cd-Acute-8	Rathore and Khangarot 2003		
Basommatophora	Lymnaeidae	Pond snail (juvenile, stage II, 9 wk), *Lymnaea stagnalis*	1,735	718.0	2.416	Cd-Acute-9	Coeurdassier et al. 2004	2.016	2.016
Basommatophora	Lymnaeidae	Pond snail (adult, 20 wk), *Lymnaea stagnalis*	1,670	1,051	1.590	Cd-Acute-10	Coeurdassier et al. 2004		
Basommatophora	Lymnaeidae	Pond snail (juvenile, 25 mm), *Lymnaea stagnalis*	350.8	164.3	2.135	Cd-Acute-12	Pais 2012		
Basommatophora	Physidae	Snail (adult, 3.3-15 mm), *Physa acuta*	1,619	1,375	1.177	Cd-Acute-14	Woodard 2005	1.177	1.177
Diplostraca	Daphniidae	Cladoceran (<24 hr), *Ceriodaphnia dubia*	30.54	13.76	2.220	Cd-Acute-17	Shaw et al. 2006	2.220	2.220
Diplostraca	Daphniidae	Cladoceran (<24 hr), *Daphnia magna*	170.8	13.67	12.49	Cd-Acute-19	Shaw et al. 2006	4.580	4.580
Diplostraca	Daphniidae	Cladoceran (<24 hr), *Daphnia magna*	517.6	308.3	1.679	Cd-Acute-22	Perez and Beiras 2010		
Decapoda	Cambaridae	Crayfish (adult), *Orconectes virilis*	6,007	2,427	2.475	Cd-Acute-30	Mirenda 1986	2.475	2.475
Ephemeroptera	Heptageniidae	Mayfly (nymph), *Rhithrogena hageni*	10,924	2,080	5.251	Cd-Acute-35	Brinkman and Vieira 2007; Brinkman and Johnston 2008	5.251	5.251
Salmoniformes	Salmonidae	Rainbow trout (8.8 g), *Oncorhynchus mykiss*	3.055	1.759	1.737	Cd-Acute-47	Phipps and Holcombe 1985	2.067	2.067

Order	Family	Species	LC_{50} (µg/L)	LC_{05} (µg/L)	LC_{50}:LC_{05}	C-R Curve Label	Reference	Species-level TAF (LC_{50}:LC_{05})	Genus-level TAF (LC_{50}:LC_{05})
Salmoniformes	Salmonidae	Rainbow trout (juvenile, 18.3 g), *Oncorhynchus mykiss*	1.682	0.5849	2.876	Cd-Acute-48	Stubblefield 1990		
Salmoniformes	Salmonidae	Rainbow trout (36 g), *Oncorhynchus mykiss*	2.679	1.683	1.591	Cd-Acute-49	Davies et al. 1993		
Salmoniformes	Salmonidae	Rainbow trout (36 g), *Oncorhynchus mykiss*	7.052	3.007	2.345	Cd-Acute-53	Davies et al. 1993		
Salmoniformes	Salmonidae	Rainbow trout (fry, 1.0 g), *Oncorhynchus mykiss*	2.773	1.726	1.606	Cd-Acute-55	Davies and Brinkman 1994b		
Salmoniformes	Salmonidae	Rainbow trout (fry, 1.0 g), *Oncorhynchus mykiss*	2.152	1.116	1.928	Cd-Acute-58	Davies and Brinkman 1994b		
Salmoniformes	Salmonidae	Rainbow trout (fry, 2.5 g), *Oncorhynchus mykiss*	10.14	5.298	1.914	Cd-Acute-60	Davies and Brinkman 1994b		
Salmoniformes	Salmonidae	Rainbow trout (263 mg), *Oncorhynchus mykiss*	0.6500	0.3493	1.861	Cd-Acute-61	Stratus Consulting 1999		
Salmoniformes	Salmonidae	Rainbow trout (659 mg), *Oncorhynchus mykiss*	0.4134	0.2108	1.961	Cd-Acute-62	Stratus Consulting 1999		
Salmoniformes	Salmonidae	Rainbow trout (1,150 mg), *Oncorhynchus mykiss*	0.4634	0.2174	2.132	Cd-Acute-63	Stratus Consulting 1999		
Salmoniformes	Salmonidae	Rainbow trout (1,130 mg), *Oncorhynchus mykiss*	0.3528	0.2237	1.577	Cd-Acute-64	Stratus Consulting 1999		
Salmoniformes	Salmonidae	Rainbow trout (299 mg), *Oncorhynchus mykiss*	1.210	0.3198	3.784	Cd-Acute-65	Stratus Consulting 1999		
Salmoniformes	Salmonidae	Rainbow trout (289 mg), *Oncorhynchus mykiss*	2.548	1.042	2.445	Cd-Acute-66	Stratus Consulting 1999		
Salmoniformes	Salmonidae	Brown trout (fingerling, 22.4 g), *Salmo trutta*	2.732	0.9770	2.797	Cd-Acute-76	Stubblefield 1990	2.797	2.797
Salmoniformes	Salmonidae	Bull trout (0.200 g), *Salvelinus confluentus*	0.9828	0.4530	2.169	Cd-Acute-79	Stratus Consulting 1999		
Salmoniformes	Salmonidae	Bull trout (0.221 g), *Salvelinus confluentus*	0.9994	0.3656	2.734	Cd-Acute-80	Stratus Consulting 1999	2.402	2.402
Salmoniformes	Salmonidae	Bull trout (0.0842 g), *Salvelinus confluentus*	3.200	1.254	2.552	Cd-Acute-82	Stratus Consulting 1999		

Order	Family	Species	LC_{50} (µg/L)	LC_{05} (µg/L)	LC_{50}:LC_{05}	C-R Curve Label	Reference	Species-level TAF (LC_{50}:LC_{05})	Genus-level TAF (LC_{50}:LC_{05})
Salmoniformes	Salmonidae	Bull trout (0.0727 g), *Salvelinus confluentus*	5.942	2.700	2.201	Cd-Acute-83	Stratus Consulting 1999		
Cypriniformes	Cyprinidae	Red shiner (adult, 0.80-2.0 g), *Cyprinella lutrensis*	6,731	4,903	1.373	Cd-Acute-85	Carrier 1987; Carrier and Beitinger 1988a	1.373	1.373
Cypriniformes	Cyprinidae	Zebrafish (adult), *Danio rerio*	15,631	8,012	1.951	Cd-Acute-86	Vergauwen 2012; Vergauwen et al. 2013	1.710	1.710
Cypriniformes	Cyprinidae	Zebrafish (adult), *Danio rerio*	12,384	8,263	1.499	Cd-Acute-87	Vergauwen 2012; Vergauwen et al. 2013		
Anura	Pipidae	African clawed frog, *Xenopus laevis*	3,314	1,447	2.290	Cd-Acute-101	Sunderman et al. 1991	2.290	2.290

2.1.1.3 Calculating Dwarf Wedgemussel Acute Cadmium Low Effect Threshold

Dividing the estimated dwarf wedgemussel LC_{50} value (65.58 µg/L) by the acute MAF (2.310) results in an acute low effect threshold concentration of 28.39 µg/L (normalized to a hardness of 100 mg/L as CaCO3).

2.1.1.4 Dwarf Wedgemussel: Acute Cadmium Effects Determination

The acute cadmium CMC at a hardness of 100 mg/L as $CaCO_3$ (1.9 µg/L total Cd), is nearly 15 times lower than the dwarf wedgemussel acute cadmium low effect threshold of 28.39 µg/L total cadmium. The dwarf wedgemussel acute low effect threshold concentration, calculated as described above based on data from continuous laboratory exposures, is greater than the corresponding criterion magnitude. As a result, refined assessment and consideration of the criterion duration is not necessary, and approval of the acute freshwater cadmium water quality standard may affect, but is Not Likely to Adversely Affect (NLAA) the dwarf wedgemussel.

2.1.2 Dwarf Wedgemussel Chronic Cadmium Residential Exposure Effects Assessment

2.1.2.1 Identifying Chronic Data

High quality species-level or genus-level chronic toxicity data are not available for the dwarf wedgemussel. Family-level chronic toxicity data were, therefore, used to determine a chronic toxicity value (i.e., EC_{20}) of 11.29 µg/L (normalized to a total hardness of 100 mg/L as $CaCO_3$) representative of the dwarf wedgemussel (Table 10). The Unionidate Family Mean Chronic Value (FMCV) is based on a single chronic toxicity assay with the fatmucket mussel (endpoint = juvenile survival). This assay is the only mussel data used to derive the chronic criterion. Unionidae chronic toxicity data were obtained from Appendix C of USEPA (2016) and were used to derive the chronic criterion.

Table 10. Data used to derive the FMCV representative of dwarf wedgemussel sensitivity to cadmium.

Common	Species	SMCV [a b] (µg/L)	Genus	GMCV[a] (µg/L)	Family	FMCV[a] (µg/L)
Fatmucket	*Lampsilis siliquoidea*	11.29	*Lampsilis*	11.29	*Unionidae*	11.29
Dwarf wedge	*Alasmidonta heterodon*	N/A	*Alasmidonta*	N/A		

[a] Chronic toxicity data have been normalized to a hardness of 100 mg/L as $CaCO_3$ and expressed as total cadmium, consistent with Appendix C of the 2016 Cadmium 304(a) Aquatic Life Criteria document (USEPA 2016).

[b] The single Species Mean Chronic Value (SMCV) used to derive the FMCV was obtained from Appendix C of the 2016 Cadmium 304(a) Aquatic Life Criteria document.

2.1.2.2 Deriving EC_{20} to EC_5 Chronic Adjustment Factor

Raw chronic toxicity data are available from the same test (Wang et al. 2010) used to calculate the Unionidae FMCV representative of the dwarf wedgemussel; however, the underlying C-R model (Cd-Chronic-9) lacks partial effects and does not provide a unique solution resulting in questionable EC_x estimates, particularly when estimating low-level effects concentrations (see Appendix VT.4). No other chronic toxicity tests with C-R data are available for the Order Unionoida.

As a result, EPA obtained and analyzed raw C-R data for all tests used to derive the chronic criterion (USEPA 2016 Appendix C underlined values) where such data were reported or could be obtained to derive a chronic vertebrate TAF or chronic MAF, if necessary (i.e., if the vertebrate and invertebrate-level chronic TAFs differ from one another).

Raw chronic toxicity data were fit to C-R models using EPA's TRAP software to calculate EC_{20} and corresponding EC_5 values for 40 tests representing 17 species (8 invertebrate and 9 fish species). C-R models were excluded from TAF and MAF calculation if 1) models did not exhibit a unique solution and were flagged by TRAP as having inadequate partials; 2) models did not include observations in the region of interest which did not allow TRAP to accurately model a no-response plateau; and 3) models exhibited incongruities such as no or poor fit to key points or excessive noise in the C-R relationship. After exclusion of unacceptable or questionable EC_{20}:EC_5 ratios, 13 ratios remained resulting in three genus-level EC_{20}:EC_5 ratios for invertebrate species (arithmetic mean = 1.779 µg/L, variance = 0.07706 µg/L) and four genus-level EC_{20}:EC_5 ratios for vertebrate species (arithmetic mean = 1.332 µg/L, variance = 0.008872 µg/L). Analysis of the two means via a two-sample t-test assuming unequal variances ($\alpha = 0.05$) indicated that the means are the same (*t stat [2.677] < t critical for two tail [4.303]*). As a result, the chronic MAF was used to transform the GMCV applicable dwarf wedgemussel to a chronic low effect threshold concentration.

Table 11 provides the seven genus-level EC_{20}:EC_5 ratios used to derive the chronic MAF. Individual test ratios ranged from 1.229 to 2.097. The chronic MAF calculated as the geometric mean of all genus-level EC_{20}:EC_5 ratios is 1.502 (see Appendix VT.3 [attached as a separate file: *Appendix_VT_Cadmium_C_R_Data*] for raw toxicity test data, TRAP models and outputs for the 13 chronic cadmium toxicity tests used to derive the chronic MAF; Appendix VT.4 includes the raw toxicity data, TRAP models and outputs for all unacceptable and questionable cadmium toxicity tests).

Table 11. Chronic EC_{20}:EC_5 ratios from analysis of 13 high-quality chronic cadmium toxicity tests with freshwater aquatic organisms used to derive a chronic cadmium MAF representative of the dwarf wedgemussel.

Order	Family	Species	EC_{20} (µg/L)	EC_{05} (µg/L)	EC_{20}:EC_{05}	C-R Curve Label	Reference	Species-level TAF (EC_{20}:EC_{05})	Genus-level TAF (EC_{20}:EC_{05})
N/A[a]	Aeolosomatidae	Oligochaete, *Aeolosoma headleyi*	57.35	27.35	2.097	Cd-Chronic-1	Niederlehner et al. 1984	2.097	2.097
Diplostraca	Daphniidae	Cladoceran, *Ceriodaphnia dubia*	4.940	3.352	1.474	Cd-Chronic-12	Southwest Texas State University 2000	1.584	1.584
Diplostraca	Daphniidae	Cladoceran, *Ceriodaphnia dubia*	5.505	3.235	1.702	Cd-Chronic-13	Southwest Texas State University 2000		
Diplostraca	Daphniidae	Cladoceran, *Daphnia magna*	0.2118	0.1059	2.000	Cd-Chronic-15	Chapman et al. Manuscript	1.657	1.657
Diplostraca	Daphniidae	Cladoceran, *Daphnia magna*	6.166	4.489	1.374	Cd-Chronic-17	Bodar et al. 1988b		
Salmoniformes	Salmonidae	Rio Grande cutthroat trout *Oncorhynchus clarkii virginalis*	2.354	1.659	1.419	Cd-Chronic-24	Brinkman 2012	1.419	1.365
Salmoniformes	Salmonidae	Rainbow trout, *Oncorhynchus mykiss*	2.283	1.774	1.287	Cd-Chronic-26	Davies et al. 1993	1.312	
Salmoniformes	Salmonidae	Rainbow trout, *Oncorhynchus mykiss*	4.956	3.719	1.333	Cd-Chronic-27	Davies et al. 1993		
Salmoniformes	Salmonidae	Rainbow trout, *Oncorhynchus mykiss*	4.315	3.272	1.319	Cd-Chronic-28	Davies et al. 1993		
Salmoniformes	Salmonidae	Brown trout, *Salmo trutta*	5.187	4.221	1.229	Cd-Chronic-42	Brinkman and Hansen 2004a; 2007	1.229	1.229
Cyprinodontiformes	Cyprinodontidae	Flagfish, *Jordanella floridae*	5.018	3.470	1.446	Cd-Chronic-48	Spehar 1976	1.446	1.446
Scorpaeniformes	Cottidae	Mottled sculpin, *Cottus bairdii*	1.762	1.329	1.326	Cd-Chronic-52	Besser et al. 2007	1.289	1.289
Scorpaeniformes	Cottidae	Mottled sculpin, *Cottus bairdii*	1.285	1.026	1.252	Cd-Chronic-53	Besser et al. 2007		

[a] N/A; not available, no order listed in the Integrated Taxonomic Information System (www.itis.gov) for the species.

2.1.2.3 Calculating Dwarf Wedgemussel Chronic Cadmium Low Effect Threshold

Dividing the estimated dwarf wedgemussel EC_{20} value (11.29 µg/L; family-level surrogate) by the chronic MAF (1.502) results in a chronic low effect threshold concentration of 7.517 µg/L (total cadmium, normalized to a hardness of 100 mg/L as $CaCO_3$).

2.1.2.4 Dwarf Wedgemussel: Chronic Cadmium Effects Determination

The cadmium CCC of 0.79 µg/L total cadmium (at a hardness of 100 mg/L as $CaCO_3$) is over 9.5 times lower than the dwarf wedgemussel chronic cadmium low effect threshold concentration of 7.517 µg/L total cadmium. The dwarf wedgemussel chronic low effect threshold concentration, based on continuous laboratory exposures, is greater than the corresponding criterion magnitude. As a result, refined assessment and consideration of the criterion duration is not necessary, and approval of the chronic cadmium freshwater quality standard may affect, but is Not Likely to Adversely Affect (NLAA) the dwarf wedgemussel.

2.1.3 Dwarf Wedgemussel, Prey Effects Assessment

The dwarf wedgemussel filters phytoplankton and zooplankton from the water column as a primary food source, with phytoplankton being relatively insensitive to acute and chronic cadmium exposures. For example, USEPA (2016) states, "*Available data for aquatic plants and algae were reviewed to determine if they were more sensitive to cadmium than aquatic animals... Effect concentrations for freshwater plants and algae were well above the freshwater criteria...and it was therefore unnecessary to develop criteria based on the toxicity of cadmium to aquatic plants…*" Acute toxicity data used to derive the acute freshwater cadmium criterion (Table 7 of USEPA 2016) indicate fish are the most sensitive to acute cadmium exposures, with pelagic crustaceans (e.g., zooplankton) being less sensitive and, therefore, adequately protected from acute cadmium exposures. Pelagic crustaceans (*Hyalella* and *Ceriodaphnia*) did comprise the two most-sensitive genera to chronic cadmium exposures (Table 9 of USEPA 2016); however, a large portion of individuals within the most sensitive genera are not anticipated to be affected because chronic toxicity values (i.e., EC_{20} values) are based on exposure durations significantly longer (e.g., 7 to 28 days for invertebrate tests) than the chronic criterion duration (i.e., 4 days). Further, chronic effects on a large portion of zooplankton (which is not an anticipated effect of the proposed actions) would translate minimally to the dwarf wedgemussel prey base because mussels also rely on phytoplankton, which is tolerant to cadmium exposures (USEPA 2016).

Because criteria are derived to protect the broad aquatic community (including zooplankton and phytoplankton) and the dwarf wedgemussel is not a specialized feeder, instead relying on a range of pelagic organisms, EPA approval of Vermont acute and chronic freshwater cadmium standards may affect, but is not likely to adversely affect (NLAA) the dwarf wedgemussel through effects to its prey.

2.1.4 Dwarf Wedgemussel, Host Fish Effects Assessment

The dwarf wedgemussel relies on host fish such as mottled sculpin to support the glochidia stage of its development. Dwarf wedgemussel reproduction and survival may be affected if host fish populations, on which glochidia may rely during the parasitic portion of the mussel's life cycle, were limited as a result of cadmium exposures specified by the acute and chronic criteria magnitude and duration. The objective of this refined effects assessment was to determine if dwarf wedgemussel host fish are sensitive to cadmium at exposure magnitudes and durations specified by USEPA (2016).

Methods:

The residential exposure effects assessment for the dwarf wedgemussel focused on identifying acute and chronic low effect thresholds (i.e., acute LC_5 and chronic EC_5) that were species specific. Rather than a species-specific approach to identify possible effects to host fish, EPA compiled acute and chronic cadmium toxicity values for host fish species (or surrogate species[3]) to derive acute and chronic species sensitivity distributions (SSDs). Acute and chronic SSDs were then used to calculate acute and chronic hazard concentration at the 5^{th} percentile (HC_5) that represent a concentration that was protective of low-level effects to 95% of fish genera that may be dwarf wedgemussel host fish.

- *Identification of Dwarf Wedgemussel Host Fish*:

Dwarf wedgemussel host fish species were initially identified at the suggestion of USFWS to consider sculpin species as potential hosts (personal communication between USFWS New England Field Office and EPA Region 1, Sept. 2019). The suggestion by USFWS was further supplemented by searching the USFWS Environmental Conservation Online System (ECOS) for recent technical documents pertaining to the dwarf wedgemussel that contained host fish information. USFWS (2019; Table 3 of the USFWS 5-year Review; Table 11 below) provided a review of all host fish species. Species in Table 12 were considered as possible host fish species for the parasitic life stage of the mussel.

[3] Fish species from the 2016 acute and chronic cadmium criteria species sensitivity distribution were retained in the dwarf wedgemussel host fish-specific SSDs if they were in the same Order of a host fish. Species in the same Order respond similarly to pollutant exposures, especially for cadmium, which does not have a targeted mode of action and generally affects all freshwater fish species similarly by disrupting calcium homeostasis and causing oxidative damage on gills (USEPA 2016).

Table 12. Host fish species, and supporting data and documentation.[a]

Potential DWM Fish Hosts Evaluated	Lab or Field	Glochidia Origin	Reference
tessellated darter (*Etheostoma olmstedi*), johnny darter (*E. nigrum*), and mottled sculpin (*Cottus bairdi*)	Lab	Tar River, NC	Michaelson and Neves 1995
slimy sculpin (*C. cognatus*), Atlantic salmon (*Salmo salar*) juveniles and parr	Lab	Ashuelot River, NH	Wicklow 2004
tessellated darter	Field	Mill River, MA	McLain and Ross 2005
pirate perch (*Aphredoderus sayanus*), redbreast sunfish (*Lepomis auritus*), green sunfish (*L. cyanellus*), bluegill (*L. macrochirus*), bluehead chub (*Nocomis leptocephalus*), highfin shiner (*Notropis altipinnis*), swallowtail shiner (*Notropis procne*), white shiner (*Luxilus albeolus*), pinewoods shiner (*Lythrurus matutinus*), fantail darter (*E. flabellare*), johnny darter, chainback darter (*Percina nevisense*), Roanoke darter (*P. roanoka*)	Lab	Tar River, NC	Levine *et al*. 2011
tessellated darter	Field	Ashuelot River, NH, Flat Brook, NJ	St. John White *et al.* 2017
tessellated darter, slimy sculpin, and Atlantic salmon parr	Lab	Ashuelot River, NH	St. John White *et al.* 2017
tessellated darter, slimy sculpin, mottled sculpin, shield darter (*Percina peltata*), Atlantic salmon parr, shield darter (*Percina peltata*), banded killifish (*Fundulus diaphanus*)	Lab	Flat Brook, NJ	St. John White *et al.* 2017
(poor hosts), brown trout (*Salmo trutta*) (poor hosts), and striped bass (*Morone saxatillis*)			
Atlantic salmon parr	Lab	Mill River, Neversink River	St. John White *et al.* 2017

[a]Table obtained directly from USFWS (2019) that outlines dwarf wedgemussel host fish species. Note, blank spaces in the second to last row were the result of compiling the table from USFWS (2019) which spanned two pages. The second to last row represents lab data from Flat Brook, NJ from St. John White et al. (2017).

- *Cadmium Toxicity Data Acquisition & Derivation of Acute and Chronic HC_5 Values:*

Host fish species in Table 12 were cross walked with the 2016 cadmium criteria acute and chronic SSDs (see Table 7 and Table 9 of USEPA [2016], respectively) to identify host species (or surrogate species within in the same Order as host species[3]) with high quality acute and/or chronic cadmium toxicity data (see Tables 13 and 15). All species that were not within the same Order as a host fish species were removed from the acute and chronic SSDs to derive host fish-specific SSDs. The host fish-specific SSDs were compiled using acute and chronic toxicity data that had been normalized to a hardness of 100 mg/L (USEPA 2016). The acute and chronic host fish-specific SSDs contained species that served as direct hosts but also contained species that were retained to provide surrogate acute and chronic values for untested direct host species.

The chronic host fish-specific SSD was used to calculate a chronic HC_5 (USEPA 1985), representing 20% chronic effects to the 5th centile of sensitive host fish genera under long-term exposure scenarios (USEPA 1985). The acute host fish-specific SSD was used to calculate a final acute value (FAV) at the fifth percentile of the distribution. The FAV, representing 50% acute effects to the 5th centile of sensitive genera, was then divided by 2.0 to calculate the acute HC_5. Dividing the FAV by 2.0 results in an HC_5 that is representative of low-level effects (e.g., 0 – 10% effects; indistinguishable from unexposed control organisms) to the 5th centile of sensitive genera (USEPA 1985).

- *Comparing Dwarf Wedgemussel Acute and Chronic Host Fish HC_5 to Criteria Magnitudes*

The acute HC_5 was compared to the acute cadmium criterion magnitude (at hardness = 100 mg/L). If the acute HC_5 was greater than the acute criterion magnitude, then the host fish species were considered adequately protected from acute cadmium exposures by the acute cadmium criterion (USEPA 2016). Similarly, the chronic HC_5 was compared to the chronic cadmium criterion magnitude (at hardness = 100 mg/L). If the chronic HC_5 was greater than the chronic criterion magnitude, then host fish species were considered adequately protected from long-term continuous chronic cadmium exposures by the chronic cadmium criterion (USEPA 2016).

Results:

The acute dwarf wedgemussel host species-specific SSD contained 30 species across 22 genera (Table 13). The chronic host species-specific SSD contained 15 species across 10 genera (Table 15). Because both SSDs contain less than 59 genera, the acute and chronic HC_5 values are both based on the four most sensitive genera (USEPA 1985).

The acute dwarf wedgemussel host species-specific HC_5 (hardness = 100 mg/L) was 2.1 µg/L (Table 14), slightly greater than the acute criterion magnitude of 1.8 µg/L. The chronic host species-specific HC_5 (hardness = 100 mg/L) was 1.2 µg/L (Table 16), greater than the chronic criterion magnitude of 0.72 µg/L.

Discussion and Conclusions:

Both the acute and chronic dwarf wedgemussel host species-specific HC_5 values were greater than their corresponding criteria magnitudes, indicating host fish species are tolerant to acute and chronic cadmium exposure magnitudes and durations specified by the cadmium criteria (USEPA 2016). Consequently, dwarf wedgemussel glochidia will not experience biological effects through reductions in host fish if cadmium were to exist at criteria magnitudes in all Vermont freshwaters for extended periods of time.

Moreover, the water quality standard approval action does not imply that cadmium will exist at criteria magnitudes in all Vermont freshwaters for extended periods of time. Rather, it's a simplified and conservative assumption used in this assessment as a conservative screening-level approach. For example, criteria are derived from tests that expose organisms to continuous cadmium concentrations for durations that are significantly longer than those specified in the acute and chronic criteria. Consequently, the acute and chronic cadmium criteria magnitudes are based on conservative exposure assumptions. For example, acute effect concentrations are inherently linked to exposure duration; the longer organisms are exposed to a particular pollutant, the lower (e.g., appear more sensitive) the observed acute effect concentration is anticipated to be (up to an incipient lethal concentration). Therefore, the acute cadmium criterion magnitude and corresponding one-hour duration are conservative, considering the acute criterion magnitude is based on 96-hour continuous exposure toxicity tests. As such, results of this refined effects assessment, based on the conservative screening-level exposure assumptions, ensure effects to dwarf wedgemussel host fish species (and resultant effects to the mussel) are not likely to occur.

Consequently, EPA approval of Vermont acute and chronic freshwater cadmium standards may affect, but is not likely to adversely affect (NLAA) the dwarf wedgemussel through effects to its host fish.

Table 13. Ranked freshwater genus mean acute values (GMAV) for species within the same order as dwarf wedgemussel fish host species.[a]

Rank[b]	Genus Mean Acute Value (µg/L)	Order	Species	SMAV adjusted to 100 hardness (µg/L)	Reason retained
22	30,781	Cypriniformes	Common carp, *Cyprinus carpio*	30,781	In the same family as 5 fish hosts
21	26,837	Perciformes	Nile tilapia, *Oreochromis niloticus*	66,720	In the same order as 5 fish hosts
-	-	Perciformes	Mozambique tilapia, *Oreochromis mossambica*	10,795	In the same order as 5 fish hosts
20	12,100	Cyprinodontiformes	Mosquitofish, *Gambusia affinis*	12,100	In the same order as 1 fish host
19	7,752	Perciformes	Green sunfish, *Lepomis cyanellus*	6,276	Direct host
-	-	Perciformes	Bluegill, *Lepomis macrochirus*	9,574	Direct host
18	7,716	Cypriniformes	Red shiner, *Cyprinella lutrensis*	7,716	In the same family as 5 fish hosts
17	6,808	Perciformes	Yellow perch, *Perca flavescens*	6,808	In the same family as 6 fish hosts
16	5,947	Cypriniformes	White sucker, *Catostomus commersonii*	5,947	In the same order as 5 fish hosts
15	5,583	Cyprinodontiformes	Flagfish, *Jordanella floridae*	5,583	In the same order as 1 fish host
14	4,929	Cyprinodontiformes	Guppy, *Poecilia reticulata*	4,929	In the same order as 1 fish host
13	2,967	Cypriniformes	Zebrafish, *Danio rerio*	2,967	In the same family as 5 fish hosts
12	1,656	Cypriniformes	Goldfish, *Carassius auratus*	1,656	In the same family as 5 fish hosts
11	1,582	Cypriniformes	Fathead minnow, *Pimephales promelas*	1,582	In the same family as 5 fish hosts
10	651.3	Salmoniformes	Lake whitefish, *Coregonus clupeaformis*	651.3	In the same family as 2 fish hosts

Rank[b]	Genus Mean Acute Value (µg/L)	Order	Species	SMAV adjusted to 100 hardness (µg/L)	Reason retained
9	80.38	Cypriniformes	Bonytail, *Gila elegans (LS)*	80.38	In the same family as 5 fish hosts
8	76.02	Cypriniformes	Razorback sucker, *Xyrauchen texanus (LS)*	76.02	In the same order as 5 fish hosts
7	46.79	Cypriniformes	Colorado pikeminnow, *Ptychocheilus lucius (LS)*	46.79	In the same family as 5 fish hosts
-	-	Cypriniformes	Northern pikeminnow, *Ptychocheilus oregonensis*	N/A[b]	In the same family as 5 fish hosts
6	>15.72	Salmoniformes	Mountain whitefish, *Prosopium williamsoni*	>15.72	In the same family as 2 fish hosts
5	6.141	Salmoniformes	Cutthroat trout, *Oncorhynchus clarkii*	5.401	In the same family as 2 fish hosts
-	-	Salmoniformes	Coho salmon, *Oncorhynchus kisutch (LS)*	11.88	In the same family as 2 fish hosts
-	-	Salmoniformes	Rainbow trout, *Oncorhynchus mykiss (LS)*	3.727	In the same family as 2 fish hosts
-	-	Salmoniformes	Chinook salmon, *Oncorhynchus tshawytscha (LS)*	5.949	In the same family as 2 fish hosts
4	5.931	Perciformes	Striped bass, *Morone saxatilis*	5.931	Direct host
3	5.642	Salmoniformes	Brown trout, *Salmo trutta*	5.642	Direct host
2	4.411	Scorpaeniformes	Mottled sculpin, *Cottus bairdii*	4.418	Direct host
-	-	Scorpaeniformes	Shorthead sculpin, *Cottus confusus*	4.404	In same genus as 2 fish hosts
1	4.190	Salmoniformes	Bull trout, *Salvelinus confluentus*	4.190	In the same family as 2 fish hosts
-	-	Salmoniformes	Brook trout, *Salvelinus fontinalis*	N/A[b]	In the same family as 2 fish hosts

[a] Data were obtained from Table 7 of USEPA (2016). Fish species were retained if they were members of the same Order of a fish that may serve as a dwarf wedgemussel host according to USFWS (2019).

[b] There is a 10x diff in SMAVs for the genus, only most sensitive SMAV is used in the calculation

Table 14. Dwarf wedgemussel host fish-specific acute HC_5 calculations.[a]

N	Rank	GMAV	ln(GMAV)	$ln(GMAV)^2$	P=R/(N+1)	sqrt(P)
22	4	5.931	1.78	3.17	0.174	0.417
	3	5.642	1.73	2.99	0.130	0.361
	2	4.411	1.48	2.20	0.087	0.295
	1	4.190	1.43	2.05	0.043	0.209
	Sum:		6.43	10.42	0.435	1.282

[a] In accordance with USEPA (1985), calculations are based on the four most sensitive genera (see table A-1).

S^2 = 3.75
L = 0.986
A = 1.419
FAV = 4.134
Acute HC_5 = 2.1

Table 15. Ranked freshwater genus mean chronic values (GMCV) for species within the same order as dwarf wedgemussel fish host species.[a]

Rank[b]	Genus Mean Chronic (µg/L)	Order	Species	SMCV adjusted to 100 hardness (µg/L)	Reason retained
10	>38.66	Perciformes	Blue tilapia, *Oreochromis aureus*	>38.66[c]	In the same order as 10 fish hosts
9	16.43	Perciformes	Bluegill, Lepomis *macrochirus*	16.43	Direct host
8	14.22	Perciformes	Smallmouth bass, *Micropterus dolomieu*	14.22[c]	In the same family as 3 fish hosts
7	14.16	Cypriniformes	Fathead minnow, *Pimephales promelas*	14.16	In the same family as 5 fish hosts
6	13.66	Cypriniformes	White sucker, *Catostomus commersonii*	13.66[c]	In the same order as 5 fish hosts
5	8.723	Cyprinodontiformes	Flagfish, *Jordanella floridae*	8.723	In the same order as 1 fish host
4	3.360	Salmoniformes	Atlantic salmon, *Salmo salar*	2.389	Direct host
-	-	Salmoniformes	Brown trout, *Salmo trutta*	4.725	Direct host
3	3.251	Salmoniformes	Rio Grande cutthroat trout, *Oncorhynchus clarkii virginalis*	3.543	In the same family as 2 fish hosts
-	-	Salmoniformes	Coho salmon, *Oncorhynchus kisutch*	N/A[b]	In the same family as 2 fish hosts
-	-	Salmoniformes	Rainbow trout, *Oncorhynchus mykiss*	2.192	In the same family as 2 fish hosts
-	-	Salmoniformes	Chinook salmon, *Oncorhynchus tshawytscha*	4.426	In the same family as 2 fish hosts
2	2.356	Salmoniformes	Brook trout, *Salvelinus fontinalis*	2.356	In the same family as 2 fish hosts
-	-	Salmoniformes	Lake trout, *Salvelinus namaycush*	N/A[b]	In the same family as 2 fish hosts
1	1.470	Scorpaeniformes	Mottled sculpin, *Cottus bairdii*	1.470	Direct host

[a] Data were obtained from Table 9 of USEPA (2016). Fish species were retained if they were members of the same Order of a fish that may serve as a dwarf wedgemussel host according to USFWS (2019).
[b] Not included in the GMCV calculation because normalized EC_{20} data available for the genus.
[c] Calculated from the MATC and not EC_{20} but retained to avoid losing a SMCV.

Table 16. Dwarf wedgemussel host fish-specific chronic HC_5 calculations.[a]

N	Rank	GMAV	ln(GMAV)	$ln(GMAV)^2$	P=R/(N+1)	sqrt(P)
10	4	3.360	1.21	1.47	0.364	0.603
	3	3.251	1.18	1.39	0.273	0.522
	2	2.356	0.86	0.73	0.182	0.426
	1	1.470	0.39	0.15	0.091	0.302
	Sum:		3.63	3.74	0.909	1.853

[a] In accordance with USEPA (1985), calculations are based on the four most sensitive genera (see table A-3).

S^2 =	8.75
L =	-0.462
A =	0.199
Chronic HC_5 =	**1.2**

2.2 Effects Assessment for the Northern Long-Eared Bat (*Myotis septentrionalis*) and Indiana Bat (*M. sodalis*)

EPA's BE for the Indiana bat and the Northern long-eared bat focuses below on the effects that the cadmium criteria could cause due to ingesting potentially contaminated prey and drinking water. Because the bats do not live in the water, EPA concludes there will be no effects as a result of meaningful residential exposure.

Bats consume some combination of terrestrial and aquatic insects. Studies indicate that the Northern long-eared bat prefers terrestrial over aquatic insects, and prefers to forage in woodland over riparian areas when available (Sparks et al 2005, USEPA 2016). The Indiana bat demonstrates a strong preference for Lepidopterans (moths) (Brack and LaVal 1985, Lee and McCracken 2004, USEPA 2016), although USFWS (2007a) concluded that inconsistencies among studies of the Indiana bat's terrestrial versus aquatic insect preferences across a geographic spectrum indicate that the bat is a selective opportunist and will eat whatever is available. Lepidopterans and Coleopterans (beetles), primarily terrestrial species, make up the majority of the diet of the Northern long-eared bat (Brack and Whitaker 2001, Feldhammer et al 2009, Lee and McCracken 2004, Whitaker 2004).

The Northern long-eared and Indiana bats rely in part on emergent aquatic insects as a dietary resource and may be affected if cadmium, at water column concentrations specified by the freshwater acute or chronic criteria magnitude and duration, were to adversely affect a large portion of emergent aquatic insects. However, aquatic life criteria are based on the fifth centile of sensitive genera to ensure the broad aquatic community, including emerging aquatic insects, are adequately protected. Aquatic insects ranked among the most tolerant taxa to acute cadmium exposures (Table 17). The data suggest that emergent insects will not be affected by the acute criteria, which are between 2-5 orders of magnitude below the species' GMAVs.

Table 17. Acute insect toxicity data used to derive the acute freshwater cadmium criterion.

Genus	Genus Mean Acute Value[b] (µg/L)[a]	Genus Rank in Species Sensitivity Distribution (SSD)
Chironomus (midge)	49,052	75
Rhithrogena (mayfly)	22,138	71
Sweltsa (stonefly)	>20,132	70
Hexagenia (mayfly)	7,798	63
Ephemerella (mayfly)	4,467	53
Arctopsyche (caddisfly)	>1,637	45
Baetis (mayfly)	350.4	32

[a] Normalized to a hardness of 100 mg/L, expressed as total cadmium (corresponding acute criterion magnitude = 1.9 µg/L total cadmium).
[b] 75 GMAVs were available to derive the acute criterion, with insects ranking among the least sensitive taxa.

Chronic toxicity data related to emerging aquatic insects were relatively limited; however, a midge ranked fourth most sensitive to chronic exposures (*Chironomus* GMCV = 2.0 µg/L total cadmium, normalized to hardness of 100 mg/L) (USEPA 2016). The midge GMCV (based on the 20% effects level, or EC_{20},) is greater than the corresponding chronic criterion magnitude (0.79 µg/L total Cd, hardness = 100 mg/L), and a large portion of individuals (i.e., > 80%) are not anticipated to be affected if cadmium concentrations were hypothetically at the chronic criteria magnitude for extended time periods consistent with chronic toxicity tests (e.g., 28 – 60 days) in Vermont freshwaters (which is not the anticipated effect of the criteria). Further, the midge chronic toxicity value was based on exposure durations that were significantly longer than the 4-day chronic criterion duration.

Consequently, aquatic macroinvertebrate populations should not be adversely affected by cadmium at criteria levels.

In addition to emerging aquatic insects, the Northern long-eared and Indiana bats also rely heavily on terrestrial insects as a primary food source. In general, a number of studies indicate that terrestrial insects make up a greater percentage of these bats' diets, depending on the location (USEPA 2016, USFWS 1999). They will not be affected at all by the new criteria.

Bats may also ingest cadmium through the water they drink. Aquatic organisms are considered to be more sensitive to cadmium relative to birds and mammals (USEPA 2016), and birds and mammals are considered to be comparatively resistant to cadmium. Consequently, criteria that are protective of aquatic life are also considered to be protective of mammals and birds (including aquatic-dependent wildlife).

Based on the analysis above and because criteria are implemented conservatively and derived to protect the broad aquatic community (including emergent insects), EPA's approval of Vermont's acute and chronic freshwater cadmium criteria may affect but is Not Likely to Adversely Affect (NLAA) the Northern long-eared bat or the Indiana bat.

2.2 Effects Assessment for the Northeastern Bulrush (Scirpus ancistrochaetus)

Northeastern bulrush is a semi-aquatic sedge plant often occuring in small wetlands, sinkhole ponds, and wet depressions with seasonly-fluctuating water levels. Consequently, Northeastern bulrush may be exposed to cadmium in Vermont freshwaters. Overall, aquatic plants are comparatively less sensitive than freshwater animals. USEPA (2016) states, "*Available data for aquatic plants and algae were reviewed to determine if they were more sensitive to cadmium than aquatic animals…. Effect concentrations for freshwater plants and algae were well above the freshwater criteria*." Appendix E of USEPA (2016) summarizes acceptable freshwater toxicity data for plants. Because plants are less sensitive to cadmium exposures than animals, and the acute and chronic cadmium criteria are based on animal responses, plants are not expected to be sensitive to cadmium at acute and chronic criteria concentrations. Therefore, approval of Vermont's cadmium criteria is not likely to adversely affect the Northeastern bulrush through the effects of residential exposure. Additionally, aquatic life criteria are based on the fifth centile of sensitive genera to ensure the broad aquatic community is adequately protected, maintaining ecosystem structure and function. Because criteria are protective of the broad aquatic community, approval of Vermont's cadmium criteria may affect but is Not Likely to Adversely Affect (NLAA) the Northeastern bulrush through residential exposure.

Final Determination of Effects - Cadmium

In conclusion, EPA has determined that EPA's approval of Vermont's revised cadmium criteria is not likely to adversely affect listed species, including the dwarf wedgemussel, Indiana and Northern long-eared bats, and Northeastern bulrush. Because the new criteria are more stringent than the current criteria, they may also have a beneficial effect on the species.

The dwarf wedgemussel is insensitive to acute and chronic freshwater cadmium exposures at the respective criterion magnitudes under the adopted water quality standards. Listed species' prey items are insensitive to cadmium. Additionally, aquatic life criteria are implemented conservatively and are based on the fifth centile of sensitive genera and will, therefore, protect listed species and their prey items. As a result, approval of the acute and chronic cadmium criteria as Vermont state water quality standards is Not Likely to Adversely Affect (NLAA) aquatic and aquatic-dependent listed species through residential exposure and/or effects on prey, drinking water, and host fish for the mussel (Table 18). EPA views the cadmium criteria revision as beneficial to the conservation and protection of aquatic life, including listed species and their food sources in Vermont.

Table 18. Final effect determinations for cadmium, for aquatic and aquatic-dependent listed species occurring in Vermont that may be affected by the approval action.

Species	Final Effects Determination for Cadmium
Dwarf wedgemussel (*Alasmidonta heterodon*)	***Not Likely to Adversely Affect (NLAA)*** (residential exposure and other effects)
Northern long-eared bat (*Myotis septentrionalis*)	***NLAA*** (Residential exposure = no effect; other effects = NLAA)
Indiana bat (*M. Sodalis)*	***NLAA*** (Residential exposure = no effect; other effects = NLAA)
Northeastern bulrush (*Scirpus ancistrochaetus*)	***NLAA*** (residential exposure and other effects)

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